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EXTRACTED VERSION

OPERATION TEAPOT

Project 2.1
Gamma Exposure Versus Distance

AD 340 142

February-May 1955

Nevada Test Site

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FOREWORD

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WT-1115

OPERATION TEAPOT PROJECT 2.1

GAMMA EXPOSURE VERSUS DISTANCE

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SUMMARY SHOT DATA

SHOT	CODE NAME	DATE	TIME *	AREA	TYPE	LATITUDE & LONGITUDE OF GROUND ZERO
1	Wasp	18 February	1200	T-7-4[1]	762' Air	37° 05' 11.6856" 116° 01' 18.7366"
2	Moth	22 February	0545	T-3	300' Tower	37° 02' 52.2654" 116° 01' 15.6967"
3	Tesla	1 March	0530	T-9b	300' Tower	37° 07' 31.5737" 116° 02' 51.0077"
4	Turk	7 March	0520	T-2	500' Tower	37° 08' 18.4944" 116° 07' 03.1679"
5	Hornet	12 March	0520	T-3a	300' Tower	37° 02' 25.4043" 116° 01' 31.3674"
6	Bee	22 March	0505	T-7-1a	500' Tower	37° 05' 41.3880" 116° 01' 25.5474"
7	ESS	23 March	1230	T-10a	67' Underground	37° 10' 06.1263" 116° 02' 37.7010"
8	Apple	29 March	0455	T-4	500' Tower	37° 05' 43.9200" 116° 06' 09.9040"
9	Wasp'	29 March	1000	T-7-4[2]	740' Air	37° 05' 11.6856" 116° 01' 18.7366"
10	HA	6 April	1000	T-5[3]	36620' MSL Air	37° 01' 43.3642" 116° 03' 28.2624"
11	Post	9 April	0430	T-9c	300' Tower	37° 07' 19.6965" 116° 02' 03.8860"
12	MET	15 April	1115	FF	400' Tower	36° 47' 52.6887" 115° 55' 44.1086"
13	Apple 2	5 May	0510	T-1	500' Tower	36° 03' 11.1098" 116° 06' 09.4937"
14	Zucchini	15 May	0500	T-7-1a	500' Tower	37° 05' 41.3880" 116° 01' 25.5474"

* APPROXIMATE LOCAL TIME - PST PRIOR TO 24 APRIL, PDT AFTER 24 APRIL

[1] ACTUAL GROUND ZERO 36' NORTH, 426' WEST OF T-7-4

[2] ACTUAL GROUND ZERO 94' NORTH, 62' WEST OF T-7-4

[3] ACTUAL GROUND ZERO 36' SOUTH, 397' WEST OF T-5

ABSTRACT

The objectives of Project 2.1 were to measure the initial gamma exposure as a function of distance from various Operation Teapot detonations and to compare these measurements with predicted exposures from various standard weapons detonated under similar circumstances (as calculated by the methods given in TM 23-200, Reference 1). Primary emphasis was placed on measurements made for a device detonated at 36,620 feet MSL (Shot 10) and for an identical device detonated at 4,995 feet MSL (Shot 9). In addition, measurements were made for designated prototype weapons of essentially new design. Measurements were also made in support of other projects.

Dosimeters consisted of photographic films of five sensitivity ranges placed in NBS-type film holders. On Shot 10, film badges were placed in drop canisters provided by Project 1.1. On other events, stations were located at distances up to 3,000 yards along a radial line from ground zero.

Initial gamma data is tabulated and graphed, as RD^2-versus-D curves for eleven Operation Teapot shots, including measurements obtained at or above an altitude of 36,620 feet MSL (Shot 10). The RD^2-versus-D curves are normalized to an air density of one gram per liter for purposes of comparison. Residual gamma radiation exposure data is tabulated for Shot 7.

The normalized RD^2-versus-D curves for Shots 9 and 10 (film-badge data) show mean free paths of 344 and 308 yards, respectively, a decrease of 11 percent from Shot 9 to Shot 10.

Deviations were observed between the RD^2-versus-D curve scaled from Reference 1 and the normalized RD^2-versus-D curves for most shots. The zero intercept of the RD^2-versus-D curves were generally greater (except for Shot 2) than the zero intercept for the computed RD^2-versus-D curve for a 1-kt weapon detonated at an air density of one gram per liter. Also, the mean free path of the normalized RD^2-versus-D curves for Shots 5, 8, 4, 3, 9, 11, and 10 deviated from the mean free path of this computed curve over a range of from 9 to 25 percent.

Most Operation Teapot shot devices produced a high-neutron flux and a nonstandard gamma output; consequently, there is little physical basis to expect the gamma exposures from these devices to scale.

FOREWORD

This report presents the final results of one of the 56 projects comprising the Military Effects Program of Operation Teapot, which included 14 test detonations at the Nevada Test Site in 1955.

For overall Teapot military-effects information, the reader is referred to the "Summary Report of the Technical Director, Military Effects Program," WT-1153, which includes the following: (1) a description of each detonation including yield, zero-point location and environment, type of device, ambient atmospheric conditions, etc.; (2) a discussion of project results; (3) a summary of the objectives and results of each project; (4) a listing of project reports for the Military Effects Program.

PREFACE

The authors wish to acknowledge the work of Captain Edwin N. York of the Air Force Special Weapons Center, Kirtland AFB, Albuquerque, New Mexico, in the analysis of the Operation Teapot data, particularly for the determination of the effect of neutrons on the gamma measurements made with film dosimeters.

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Chapter 1

INTRODUCTION

1.1 OBJECTIVES

The objectives of Project 2.1 were to measure the initial gamma exposure as a function of distance from various Operation Teapot detonations and to compare these measurements with predicted exposures from various standard weapons detonated under similar circumstances (as calculated by the methods given in TM 23-200, Reference 1). Primary emphasis was placed on measurements made for a device detonated at 36,620 feet MSL (Shot 10) and for an identical device detonated at 4,995 feet MSL (Shot 9). In addition, measurements were made for designated prototype weapons of essentially new design; measurements were also made in support of other projects.

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1.2 BACKGROUND

Initial gamma radiation may be considered as that emitted during the first 30 seconds after detonation. Initial-gamma-radiation output for various nuclear devices of yields up to 250 kt has been documented on previous test operations (References 2, 3, and 4). Evans Signal Laboratory (ESL) measured total gamma radiation as a function of distance during Operations Buster-Jangle, Tumbler-Snapper, Upshot-Knothole, and Castle. During Operation Buster-Jangle, measurements (Reference 6) were made of initial plus residual exposure on the surface and underground events. During Operations Tumbler-Snapper and Upshot-Knothole, the measurements were designed to give initial-gamma readings. The Operation Castle results were mainly residual and/or fallout measurements, since the initial stations were destroyed by the first event (Reference 2). The present project was designed to extend previous measurements to include gamma-radiation measurements at burst altitude for an airburst device and to document initial gamma radiation for devices of essentially new design.

1.3 THEORY

It has been found that initial gamma exposure data from a nuclear detonation may be empirically represented by the following formula:

$$R = \frac{Se^{-\bar{\mu}D}}{D^2} \qquad (1.1)$$

Where: S is a constant representing the source strength including the conversion factor to convert γ photons into roentgens

$\bar{\mu}$ is the apparent linear absorption coefficient for hetero-energetic radiation (unit D^{-1})

D is the slant range between the source and the receiver (normally in yard units)

From Equation 1.1 it follows that:

$$\ln RD^2 = \ln S - \bar{\mu} D \qquad (1.2)$$

From the data, RD^2 is plotted as the ordinate and D as the abscissa on semilogarithmic paper. The empirical curve is fitted as the best straight line and has a slope of $-\bar{\mu}$. The apparent linear absorption coefficient, $\bar{\mu}$, and its reciprocal, $1/\bar{\mu}$, which may be defined as apparent mean free path, are determined directly from this curve. This mean free path is the distance in yards which reduces the RD^2 value to 1/e of its original value.

In order to compare gamma exposure and yield from one nuclear detonation to another, it is necessary to eliminate the variation in exposure due to changes in the air density by normalizing the exposures to a reference air density.

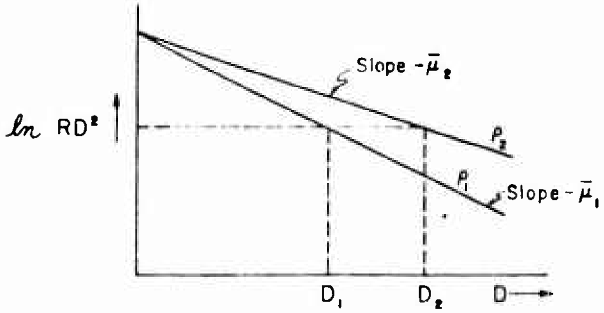

Figure 1.1 Scaling diagram.

To scale γ radiation RD^2 versus D from density ρ_1 to a new density ρ_2, where ρ is the density of the medium traversed by the γ photons, and in particular air, see Figure 1.1.

At ordinate value:

$$R_1D_1^2 = R_2D_2^2$$

$$\bar{\mu}_1D_1 = \bar{\mu}_2D_2$$

And since the apparent mass absorption of air is independent of air density:

$$\frac{\bar{\mu}_1}{\rho_1} = \frac{\bar{\mu}_2}{\rho_2}$$

Then:

$$D_2 = D_1\left(\frac{\rho_1}{\rho_2}\right) \qquad (1.3)$$

This locates the abscissa D_2 for $R_2D_2^2$, and the numerical value of R_2 is:

$$R_2 = R_1\left(\frac{\rho_2}{\rho_1}\right)^2 \qquad (1.4)$$

The RD^2-versus-D curves are normalized using Equation 1.3 and corresponding values of R are determined from Equation 1.4.

After normalizing for air density, the exposure from detonations of similar standard devices can be scaled to determine relative yields, since the initial gamma exposure is proportional to yield. Conversely, if the yields of similar devices are known the relative exposure can be calculated. According to Reference 1, effective gamma yield scales directly with yield up to about 10 kt; above 10 kt the proportionality factor is greater than unity, and is a function of relative air density.

Chapter 2

PROCEDURE

2.1 OPERATIONS

Project 2.1 participated fully in Shots 1, 2, 3, 5, 6, 9, 10, and 11, and as a support to other projects on Shots 4, 7, 8, and 12. On all shots except 7 and 12, National Bureau of Standards (NBS) film dosimeters were located along radial lines from ground zero at 100-yard intervals at slant ranges of 280 to 2,400 yards. On Shot 7, NBS dosimeters were located at every intersection of the grid network shown in Figure 2.1. NBS dosimeters were placed and recovered by Project 2.5.1 with assistance from this project. On Shot 10 NBS dosimeters were placed behind five or six aluminum windows in each of the 15 drop canisters. Three of these drop canisters (Numbers 4, 8, and 12) also were instrumented with quartz-fiber dose-time devices. In order to have some assurance of initial gamma exposures (i. e., minimum residual gamma contamination), the exposure stations for all shots except Shots 7 and 10 were located in planned upwind sectors and dosimeters were recovered as early postshot as possible. This instrumentation recovery plan was used so that the exposure from residual gamma radiation could be neglected with respect to the initial gamma exposure.

2.2 INSTRUMENTATION

The primary instrument used was the NBS photographic dosimeter, which consists of the NBS film holder loaded with two dosimeter film packets. The emulsion types making up the dosimeter packets and their useful exposure range are listed in Table 2.1, along with the betatron correction factor for each. The NBS film holder (Reference 7) consisted of a bakelite container with an 8.25-mm wall thickness covered with layers of 1.07 mm of tin and 0.30 mm of lead. A lead strip 0.78 mm thick was wrapped around the outer edge of the holder to cover the seam.

There is no simple and direct relationship between film blackening and radiation exposure, but in general, the photographic effect is a function of the incident photon energy, the response of the film being dependent on the absorption coefficient in the emulsion. Response is the ratio of the emulsion density at the energy in question to the density at a reference energy for the same exposure. Reference is usually made to the flat section of the response curve, corresponding to the Compton region. The emulsion blackening per unit exposure, caused by secondary electrons, decreases with increasing photon energy in the photoelectric and Compton regions because the absorption coefficient decreases with increasing gamma radiation energy. At higher energies, where pair production becomes significant, the reverse is true since the absorption coefficient increases with increasing energy.

Two absorption coefficients must be considered when using film in a holder; the absorption coefficient of the holder and the absorption coefficient of the film emulsion. The response of the film is proportional to its absorption coefficient. Since it is desirable to have the overall response of the film emulsion in the holder constant, the holder was designed so that its absorption versus photon energy curve matched as closely as possible the response curve of the unshielded films. Accordingly, the absorption of the holder is low where the film response is low, and therefore the transmission of the holder is relatively high where the film response is low. Throughout the energy range in which the holder absorption matches the film response, the response of the film in the holder is essentially constant.

In the NBS holder, the lead filter suppresses the lower energies sufficiently to keep the re-

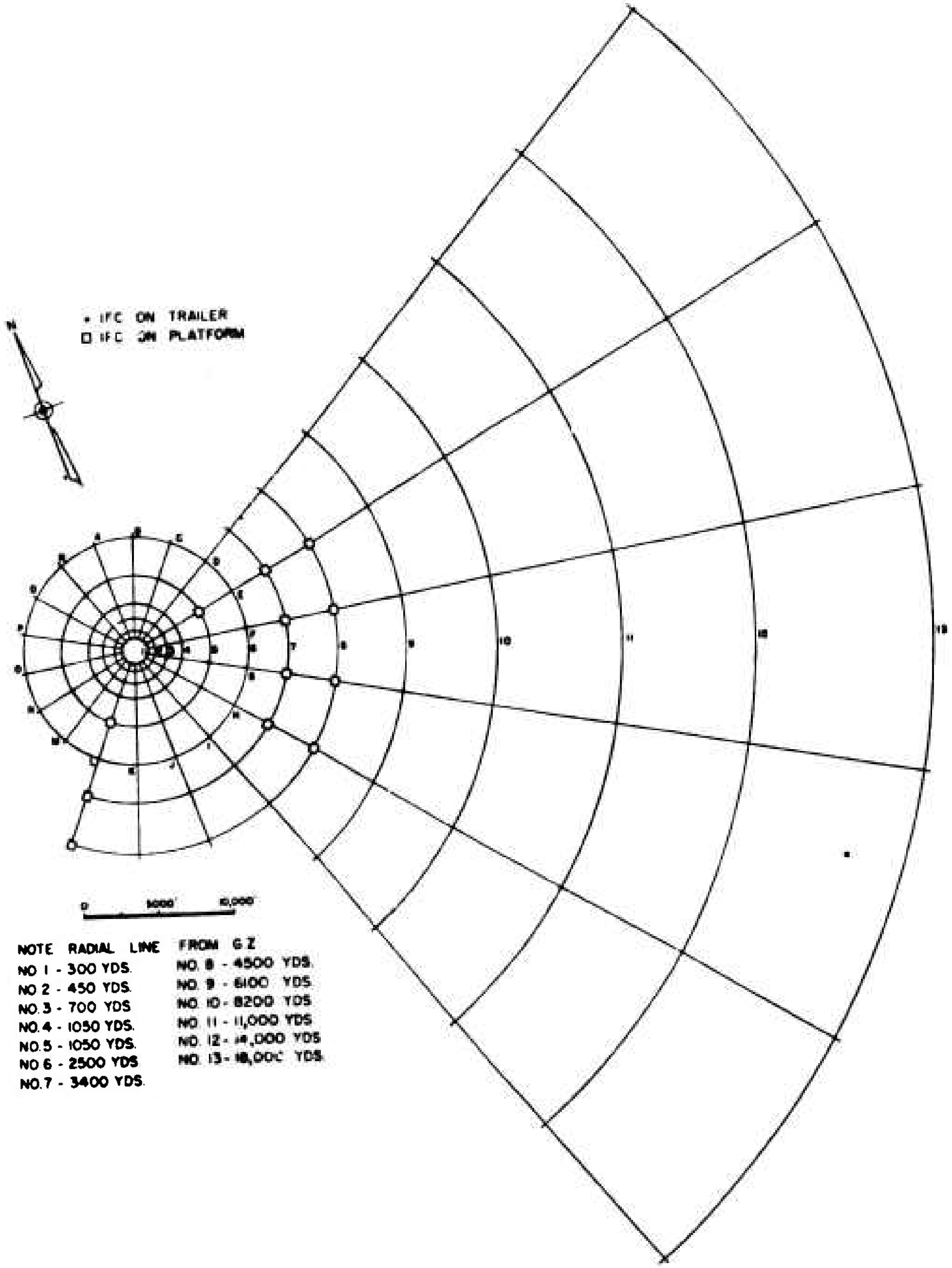

Figure 2.1 Idealized master station locator, Program 2, Shot 7.

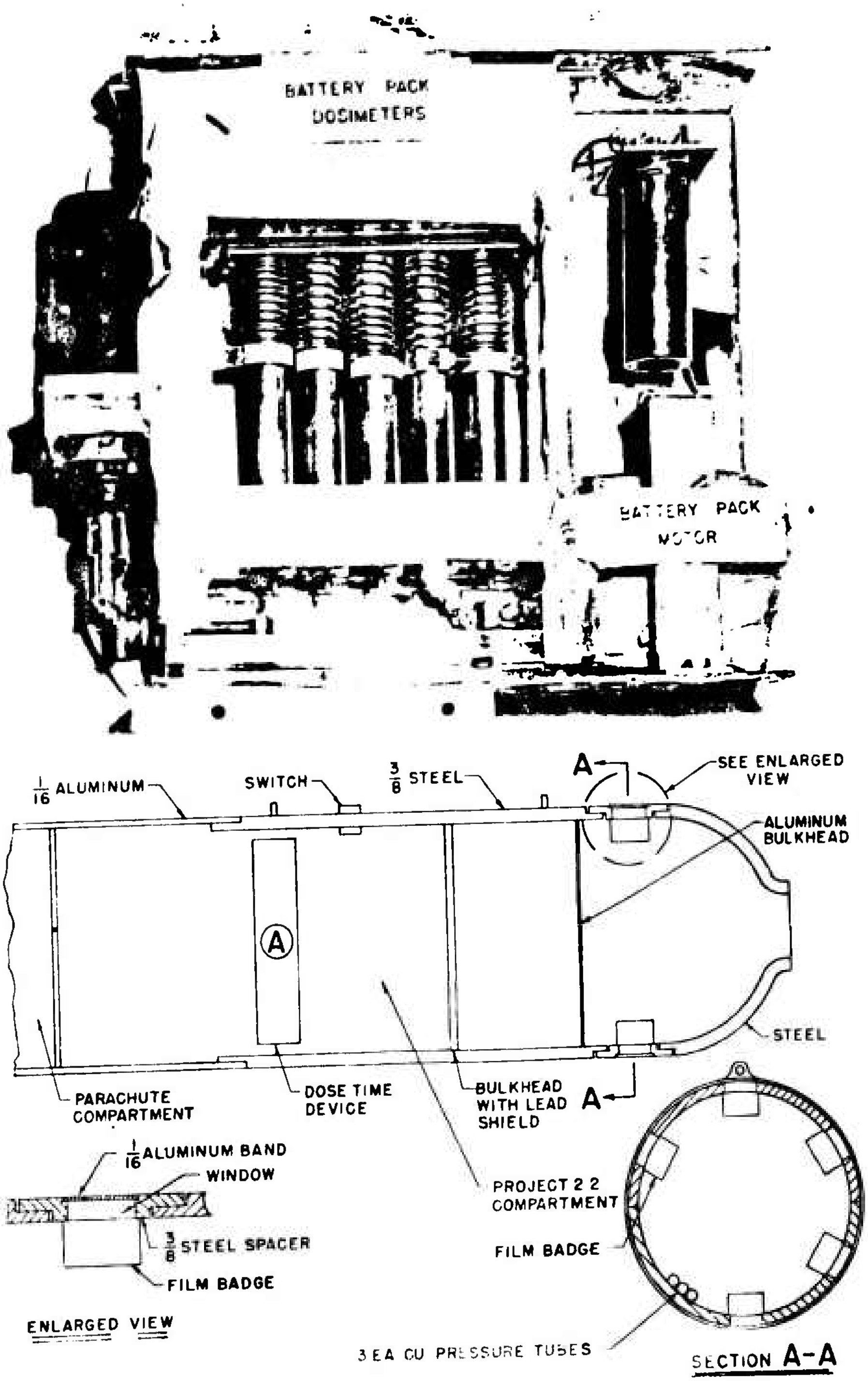

Figure 2.2 Instrumentation canister and dose-time device.

sponse linear above 115 kev. Below 115 kev the gamma radiation is attenuated heavily. The layer of tin was added to compensate for the discontinuity immediately below the K shell absorption edge of lead.

Bakelite is an air-equivalent material, i. e., same effective atomic number; therefore, the absorption of gamma rays in the bakelite layer approximates the absorption in a large volume of air. Secondary electrons produced by high energy gamma in the lead-tin filter are absorbed by the bakelite. The bakelite layer was made thick enough to provide electronic equilibrium in the holder wall for radiation from an 11-Mev betatron (Reference 8).

Since the response curves of film emulsions vary somewhat, the response of the film in the holder was more linear for some emulsions than for others. In the exposure range from 1 to 50,000 r and in the energy range from 115 kev to 10 Mev, the dosimeter is considered accurate within ± 20 percent without further knowledge of radiation quality for the following emulsion types: Dupont 502, 510, 606, 1290 and Eastman 548-0 (double-coated).

TABLE 2.1 FILM CHARACTERISTICS

Film Type	Useful Gamma Exposure Range	Slow Neutron Sensitivity	High Energy Neutron Sensitivity Percent of Neutron REP Dose	Betatron Correction Factor
	r	nvt/r		
Dupont 502	0.250 to 5	$3.2 \pm 1.7 \times 10^9$	3.9 ± 2.3	1.2
Dupont 510	2.0 to 25	$2.3 \pm 1.4 \times 10^9$	5.4 ± 3.3	1.1
Dupont 606	20 to 400	$3.4 \pm 1.8 \times 10^9$	3.6 ± 2.2	1.16
Dupont 1290	50 to 700	$3.9 \pm 2.2 \times 10^9$	3.2 ± 2.1	1.21
Eastman 548-0a	2,000 to 25,000	$4.7 \pm 1.9 \times 10^9$	5.0 ± 2.9	1.13

2.2.1 Employment. For the detonation at 36,620 feet MSL (HA event), NBS film badges were placed in each of the 15 steel instrumentation drop canisters (Figure 2.2). These badges were placed behind specially prepared aluminum windows around the circumference near the forward end of the canister. The windows were prepared by drilling 2-inch-diameter holes in the wall of the canister spaced 60 degrees apart around the circumference, and by covering the outside with a strip of 0.0625-inch aluminum sheet fastened around the circumference. There were six such windows; however, only five were usable due to interference with copper pressure tubes passing too close to the sixth window. The slant ranges of each canister at the time of detonation were furnished by Project 1.1, and the total neutron-flux data for each canister was furnished by Project 2.2. Film holders were placed in suitably modified canisters and positioned in the field at desired distances from the Shot 1 and Shot 9 detonations to allow comparison between these two devices and Shot 10.

Dose-time instruments (Figure 2.2) were placed in each of three drop canisters to determine what effect radiation from the cloud would have on the total gamma exposure data. This device consisted primarily of Bendix IM-93 dosimeters in suitable ranges, the maximum range of the chambers being 1,000 r and the minimum being 20 r. The dosimeters were kept on charge, i. e., zeroed, until after the initial burst. By a mechanical means the dosimeters were removed from the charging potential in a predetermined time sequence. The initiating action was to be determined by the release of the canisters from the strike aircraft. This action was the application of a 6-volt signal which actuated a thermal delay relay. Closing of the thermal delay relay actuated a motor which mechanically removed the zeroing potential from each dosimeter. A similar device was placed in the 800-yard canister on Shot 9 to allow comparison with the data from Shot 10.

On all events except Shots 7 and 10, NBS film holders, each loaded with two film packets, were located on radial lines extending from ground zero. The dosimeters were placed at intervals of 100 yards and at distances from 500 or 1,000 yards to 2,000 or 3,000 yards as required. For Shots 3 and 11 film holders were placed from 400 to 1,200 yards on three additional radial lines from ground zero to investigate the geometrical asymmetry of the gamma exposure.

The NBS film holders were placed with the flat side normal to the point of burst in aluminum holders and were recovered about 3 hours after the detonation. The aluminum holders were fastened to metal stakes at approximately 3 feet above the surface of the ground.

Film badges were furnished in suitable ranges to the following projects during the operation: Projects 2.4, 2.5.1, 2.5.2, 2.7.1, 2.8, 3.1, 5.1, 6.1.1, 6.2, 39.6 and 39.7. These badges were placed in selected locations by the requesting projects and returned for processing. On Shot 7, NBS dosimeters were placed by Project 2.5.1 at every intersection of the grid network as shown in Figure 2.1. This project cooperated with Projects 6.1.1 and 39.6 by sharing stations along the same radial line at all locations where the dosimeter evaluation projects had stations.

2.2.2 Calibration and Processing. The films were calibrated in NBS holders by means of a 72.5 curie Co^{60} source. The Co^{60} source was contained in a brass capsule with a wall thickness of 0.076 inches and was stored in a lead pig in an open area in the vicinity of Camp Mercury. Compressed air was used to force the capsule up and down a monel-steel tube to an aluminum top section (with a wall thickness of 0.062 inch), which was directly above a platform on which the holders were placed for calibration. The platform was about 6 feet above the lead pig to reduce the effects caused by scattering.

The source was calibrated on site using standard Victoreen r-chambers with 4-mm lucite caps. These were calibrated at the National Bureau of Standards for use at 22 C and 760-mm pressure. When these instruments were used under other atmospheric conditions, the readings were multiplied by a correction factor obtained from the following expression:

$$f = 2.576 \frac{(273 + t)}{p}$$

Where: f is the total atmospheric correction
t is the temperature in degrees Centigrade
p is the pressure in millimeters of Mercury

The film holders were placed (in fixed plastic containers) on the wooden platform at a minimum distance of 16.7 cm from the source and exposed for a minimum of 15 minutes giving a high degree of statistical accuracy to the exposure calculations. Each calibration run was timed to center about the expected time of detonation.

Following the procedure recommended by NBS, the basic calibration was performed on the Naval Ordnance Laboratory (NOL) 10-Mev betatron. Calibration curves for the films used were obtained from this betatron and at the same time from Co^{60} exposures. The Co^{60} exposures were then normalized to betatron exposures. The betatron normalization factors for the Operation Teapot films are listed in Table 2.1. These factors were determined by NBS and ESL personnel using the NOL betatron after Operation Teapot. Field exposure values based on Co^{60} calibration were betatron corrected by dividing field values by the appropriate normalization factor.

The exposed films were developed in Eastman dental X-ray film developer for 5 minutes, followed by an acetic acid stop bath for 30 seconds with vigorous agitation. The films were then immersed in Eastman Dental X-ray Fixer for 7 minutes and washed about 15 minutes. The temperatures of the solutions were held constant at 68 degrees $\pm\, ^1\!/_2$ F during processing. A set of films calibrated with the Co^{60} source was processed, along with each group of field-exposed films.

The photographic transmission densities were read on an Ansco-MacBeth Model 12 densitometer which was frequently checked for sensitivity change by means of a photographic density wedge and for zero shift by means of the zero adjustment. The densitometer measured the percentage of a narrow beam of light of a constant intensity that was transmitted by any given small area of test film. The reciprocal of this was the opacity; and the common logarithm of the opacity was the density, which was read directly from the densitometer.

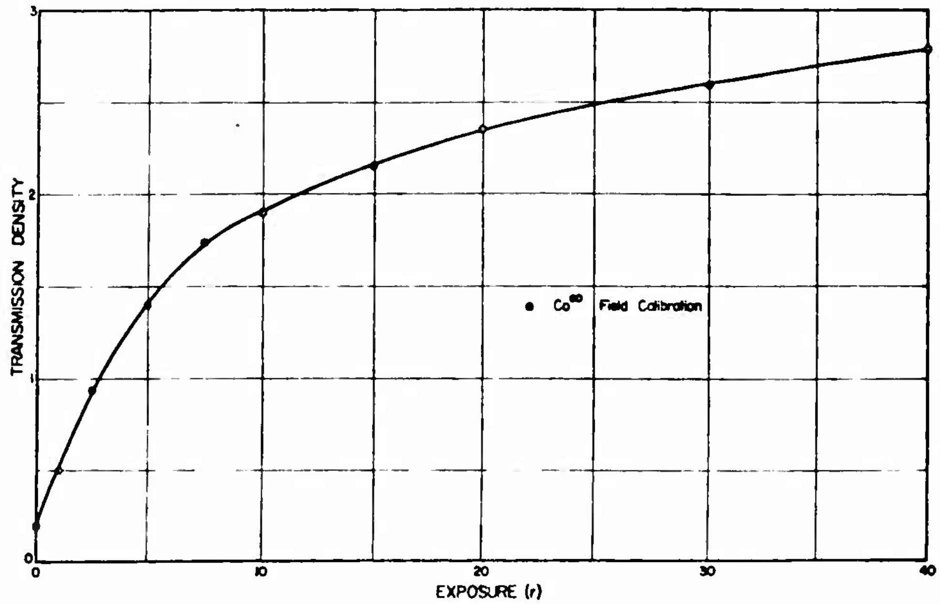

Figure 2.3 Calibration curve, Dupont 502.

The exposures recorded by the films were determined by comparing film densities with those of the Co^{60} calibrated films by means of curves of density versus exposure. Figures 2.3 through 2.7 are typical of the calibration curves. The calibration of Eastman 548-0 film, as shown in Figure 2.7, was extended by a separate calibration from 25,000 to 70,000 r for those shots that could possibly produce gamma exposures of this magnitude at any exposure station. Table 2.1 lists the ranges over which each film was used.

The films were stored in a refrigerator at 50 F and were removed approximately 24 hours before use. Any change that might have been due to temperature or aging was compensated for

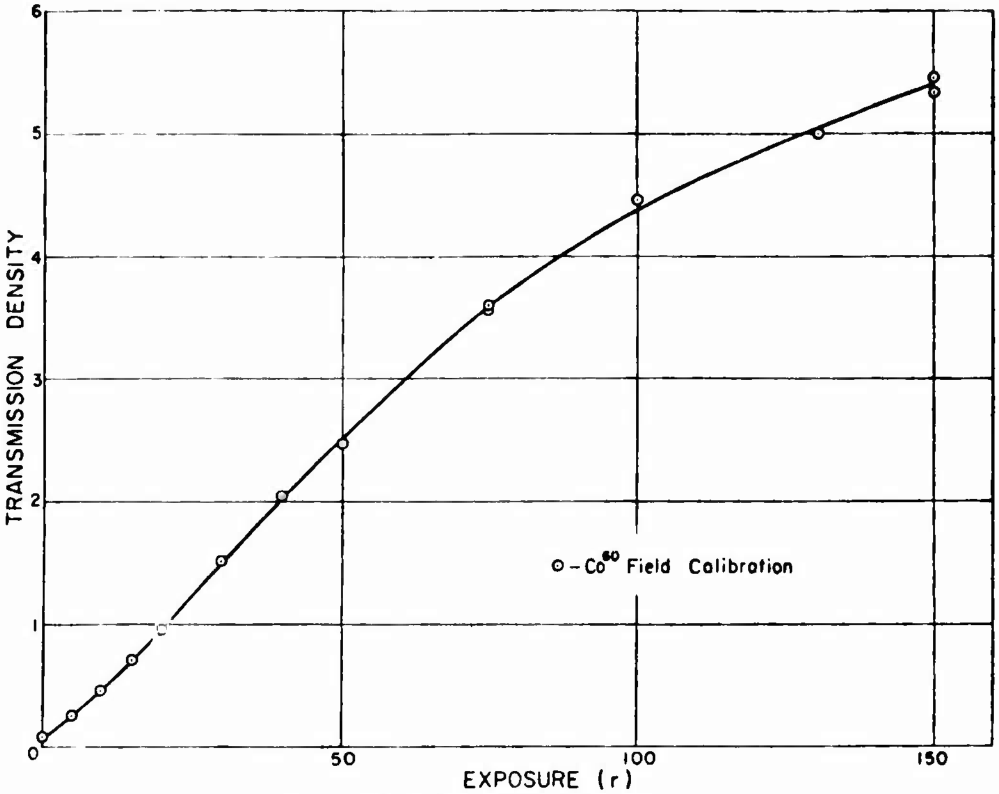

Figure 2.4 Calibration curve, Dupont 510.

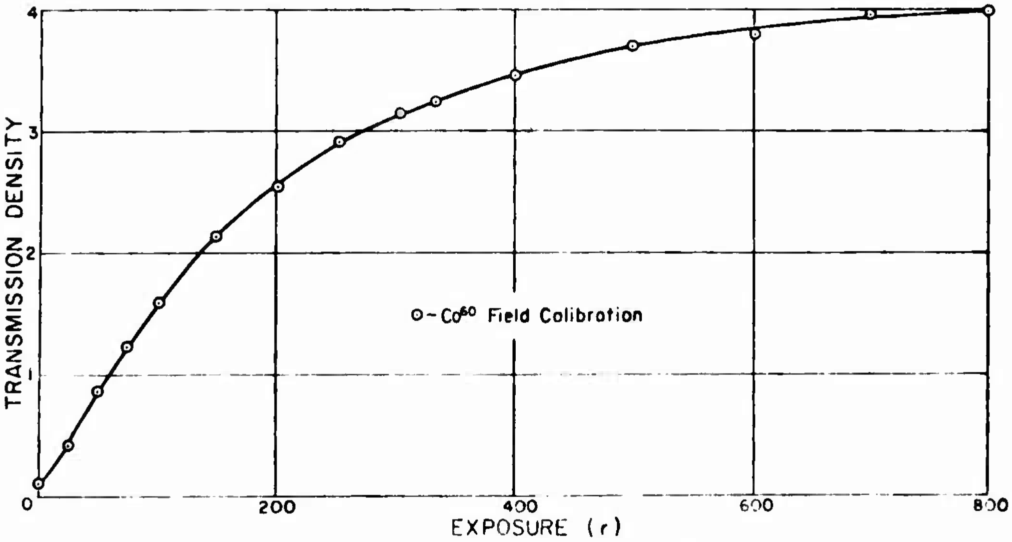

Figure 2.5 Calibration curve, Dupont 606.

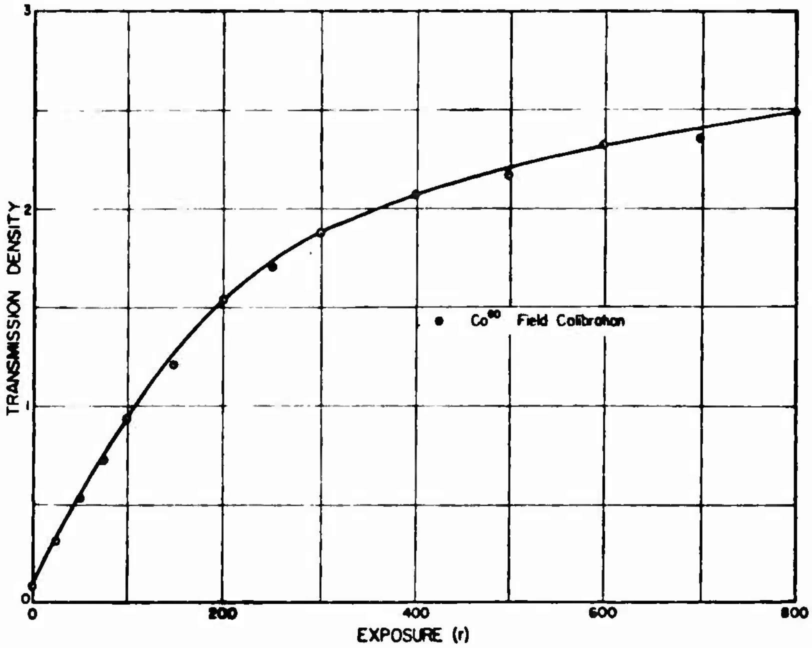

Figure 2.6 Calibration curve, Dupont 1290.

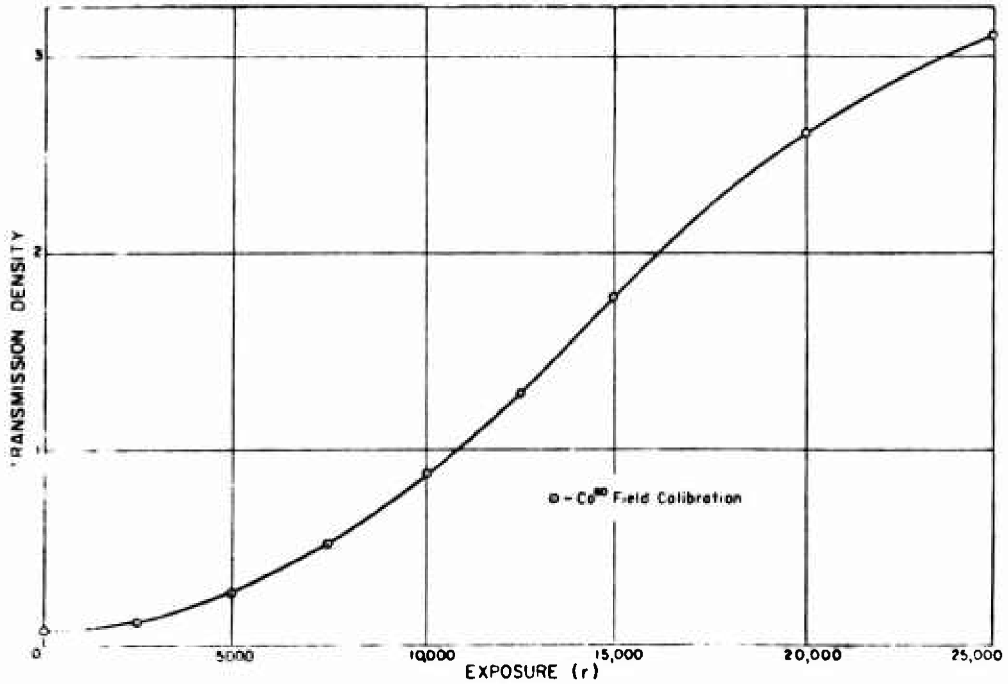

Figure 2.7 Calibration curve, Eastman 548-0.

by use of a new set of calibration films with each processing.

2.3 DATA REQUIREMENTS

The required exposure measurements were: (1) Initial gamma exposure as a function of distance for a nuclear device of 3.1 kt detonated at an altitude of 36,620 feet MSL where the measurements were to be performed to cover a combined neutron-plus-gamma radiation exposure range from 25 to 25,000 rem; (2) Gamma exposure as a function of distance for a device identical to that of Item 1 above detonated at a height of burst of 4,995 feet MSL in order to provide a field calibration of the instruments used and to provide experimental data for comparison with the predicted space variations of initial gamma exposure as a function of altitude of detonation; (3) A measurement of gamma exposure received at discrete time increments from the 4,995 feet MSL and 36,620 feet MSL detonations, to estimate the effect of radiation from the cloud on the total exposure measurements; (4) Initial gamma exposure as a function of distance from experimental devices, i. e. [redacted] where the gamma exposure as a function of distance has not previously been adequately determined. [redacted] (5) Total gamma exposure inside and outside selected structures and field fortifications in support of radiation studies conducted by Project 2.7 and for other projects performing radiation and biomedical studies. Gamma exposure resulting from the fallout caused by the underground detonation (Shot 7) was measured at stations laid out in a predetermined pattern prior to the event; (6) Gamma exposure at various stations to provide a basis for the evaluation of other types of dosimeters by Project 6.1.1a and for support measurements for all other requesting projects.

The initial gamma exposure values, after correction for the betatron calibration and neutron effect on the film emulsion, were accurate to within 30 percent, including errors due to calibration, processing, readout, and the directional response of the NBS holder.

Chapter 3

RESULTS and DISCUSSION

The gamma exposure in roentgens resulting from the first twelve shots of Operation Teapot is presented as a function of distance (slant range) in yards in Tables 3.1 through 3.12. Table 3.7 presents the Shot 7 total gamma exposure which is predominately residual gamma exposure; the other tables present initial gamma data interpreted in terms of Co^{60} and 10 Mev betatron calibrations. These tables also present the results of the correction of the data for the effect of neutrons on the film where neutron data was available. From the initial data, RD^2-versus-D curves for each shot are plotted in Figures 3.1, 3.2, 3.3 and 3.6 through 3.13. The RD^2-versus-D curves were drawn as the best straight line fitted visually to the data points. In the case of Shot 12, a least-square fit was calculated for this data (Figure 3.13). Each curve has also been normalized to a reference air density of 1.0 gram per liter, and for each normalized curve there is a curve showing the predictions computed from Reference 1 for that device detonated at the reference air density (R = 0.775). Canister position (slant range), air density, and normalized distance data for Shot 10 are reported in Table 3.13. Canister dose-time device data for Shots 9 and 10 are presented in Table 3.14. Yield, device data, zero intercept, apparent mean free path, and apparent mass absorption coefficients for each shot are presented in Table 3.15. RD^2-versus-D curves, normalized to an air density of 1 gram per liter for Shots 9 and 10, are shown in Figure 3.4 for purposes of comparison of these shots. Figure 3.5 shows the results obtained with quartz-fiber dose-time devices on Shots 9 and 10.

Reference 1 gives a method for scaling gamma yields of standard atomic weapons. From data given in Reference 1 an RD^2-versus-D curve for a 1-kt standard weapon detonated at a relative air density of 0.775 has been computed and is presented as Figure 3.14. Using the methods of Reference 1, this data was then scaled to the yields of the individual shots, and the appropriate resulting curve was added to each shot curve. For standard weapons, gamma scaling should be linear up to 10 kt, however, the low-yield high-neutron flux devices of primary interest to this project should produce a nonstandard gamma output which would cause changes in the measured gamma exposure per kt and also in the apparent mean free path. There is no physical basis for scaling the gamma exposures of these devices.

Table 3.15 summarizes the results obtained, giving shot names, yields, device data, zero intercept values from the RD^2-versus-D curves, zero intercept per kt, apparent mean free paths, and apparent mass absorption coefficients. This table also includes computed values of the above factors for a 1-kt standard weapon for comparison with the measured data.

3.1 NEUTRON EFFECTS ON FILM DOSIMETERS

Reference 9 reports the results of a detailed analysis of initial nuclear radiation from low-yield fission weapons, including the events of Operation Teapot. Air Force Special Weapons Center (AFSWC) carried out this analysis, Los Alamos Scientific Laboratory (LASL) provided the neutron exposures from the Godiva bare assembly at Los Alamos, and Evans Signal Laboratory (ESL) supplied samples of Operation Teapot and Operation Redwing film emulsions and NBS film holders; ESL also processed and interpreted these exposed films in terms of Co^{60} calibrations. This experiment yielded additional rate dependence information for these emulsions in that there was no significant change in emulsion response due to gamma exposure rate between

TABLE 3.1 GAMMA EXPOSURE, SHOT 1

Distance	Exposure		
Slant Range	Uncorrected (Co^{60} Calibration)	Betatron Corrected	Betatron and Neutron Corrected
yd	r	r	r
290	43,000	39,000	35,050
440	6,400	5,700	4,610
799	600	495	435
887	335	276	276
976	215	176	—
1,070	143	114	—
1,161	92	73	—
1,255	60	47	—
1,350	35	30	—
1,445	23	22	—
1,541	16	15	—
1,638	12	11	—
1,833	5.5	4.8	—
2,029	2.65	2.3	—

TABLE 3.2 GAMMA EXPOSURE, SHOT 2

Distance	Exposure		
Slant Range	Uncorrected (Co^{60} Calibration)	Betatron Corrected	Betatron and Neutron Corrected
yd	r	r	r
412	9,600	8,600	5,560
510	4,000	3,600	2,965
906	425	330	300
1,005	280	219	202
1,104	156	124	115
1,203	112	91	—
1,303	75	60	—
1,402	45	34	—
1,502	25	20	—
1,602	15	13.6	—
1,701	10.9	9.9	—
1,801	7.4	6.2	—
1,901	5.3	4.4	—
2,000	3.8	3.2	—

TABLE 3.3 GAMMA EXPOSURE, SHOT 3

Distance	Exposure		
Slant Range	Uncorrected (Co^{60} Calibration)	Betatron Corrected	Betatron and Neutron Corrected
yd	r	r	r
511	19,500	17,700	13,800
609	9,600	8,500	6,660
715	4,400	4,050	3,150
806	3,000	2,600	2,180
1,145	465	355	311
1,230	310	240	214
1,316	205	170	—
1,404	135	108	—
1,494	95	76	—
1,585	63	50	—
1,678	40	33	—
1,771	25	20	—

TABLE 3.4 GAMMA EXPOSURE, SHOT 4

Distance	Exposure	
Slant Range	Uncorrected (Co^{60} Calibration)	Betatron Corrected
yd	r	r
1,519	570	465
1,615	385	320
1,714	280	235
1,741	240	200
1,876	200	165
1,845	150	125
1,871	125	104
1,961	107	90
1,995	85	71
2,096	57	47
2,188	40	33
2,283	25	21
2,371	21	15
2,466	15	11.6

TABLE 3.5 GAMMA EXPOSURE, SHOT 5

Distance	Exposure		
Slant Range	Uncorrected (Co^{60} Calibration)	Betatron Corrected	Betatron and Neutron Corrected
yd	r	r	r
275	67,000	60,000	52,170
420	16,600	15,000	12,970
505	8,800	7,800	6,700
560	6,250	5,500	4,850
608	4,300	3,800	3,345
685	3,300	3,000	2,790
995	662	548	507
1,005	550	455	✓425
1,054	395	326	305
1,104	325	268	253
1,153	245	202	—
1,203	187	154	—
1,303	125	103	—
1,402	79.0	65.2	—
1,502	45.0	36.0	—
1,602	30.8	28.0	—
1,701	21.0	20.0	—
1,801	15.0	13.6	—
1,901	10.0	9.1	—
2,000	7.0	6.5	—
2,100	5.0	4.4	—

TABLE 3.6 GAMMA EXPOSURE, SHOT 6

Distance	Exposure		
Slant Range	Uncorrected (Co^{60} Calibration)	Betatron Corrected	Betatron and Neutron Corrected
yd	r	r	r
527	30,500	27,000	23,025
623	13,100	11,600	9,640
720	7,200	6,400	5,400
817	4,000	3,500	2,985
915	2,500	2,200	1,900
1,212	623	514	468
1,311	362	299	—
1,410	240	198	—
1,509	150	124	—
1,609	108	90	—
1,708	74	62	—
1,808	45	38	—
1,908	32	26	—
2,007	18	18.1	—
2,107	14	13.6	—
2,207	11	10	—
2,307	8.2	7.6	—
2,406	6.4	5.5	—
2,506	4.7	4.15	—
2,606	3.8	3.3	—
2,706	2.7	2.5	—
[illegible]	2.2	2.1	—
2,905	1.5	1.6	—
3,005	1.2	1.1	—

TABLE 3.7 GAMMA EXPOSURE, SHOT 7

Locations of exposure stations are indicated in Figure 2.1, Idealized Master Station Locator, Program 2, Shot 7. NBS dosimeters were placed and recovered by Project 2.5.1 with assistance from this project.

Station	Exposure	Station	Exposure	Station	Exposure	Station	Exposure	Station	Exposure	Station	Exposure
	r		r		r		r		r		r
A-1	17,000	B-1	22,500	C-1	13,000	G-7	250	H-7	60	I-7	26
A-2	9,000	B-2	10,400	C-2	9,000	G-8	20	H-8	—	I-8	10
A-3	1,500	B-3	3,000	C-3	1,800	G-9	14	H-9	—	I-9	10
A-4	56	B-4	1,300	C-4	—	G-10	7.6	H-10	7.4	I-10	—
A-5	2.95	B-5	7.25	C-5	—	G-11	10	H-11	—	I-11	—
A-6	0.20	B-6	0.250	C-6	—	G-12	10	H-12	10	I-12	—
D-1	20,000	E-1	25,000	F-1	25,000	G-13	10	H-13	10	I-13	—
D-2	3,300	E-2	9,000	F-2	25,000	J-1	15,000	K-1	13,000	L-1	9,000
D-3	13,000	E-3	3,300	F-3	10,000	J-2	6,000	K-2	5,000	L-2	3,000
D-4	—	E-4	—	F-4	1,000	J-3	1,600	K-3	1,600	L-3	1,000
D-5	—	E-5	—	F-5	200	J-4	675	K-4	620	L-4	850
D-6	—	E-6	—	F-6	70	J-5	250	K-5	150	L-5	5.90
D-7	0.20	E-7	500	F-7	10	J-6	90	K-6	7.2	L-6	0.45
D-8	0.20	E-8	500	F-8	—	M-1	10,000	N-1	13,000	O-1	9,500
D-9	0.20	E-9	5	F-9	10	M-2	4,000	N-2	8,500	O-2	2,500
D-10	—	E-10	10	F-10	—	M-3	—	N-3	1,450	O-3	250
D-11	10	E-11	10	F-11	10	M-4	86	N-4	50	O-4	40
D-12	10	E-12	10	F-12	10	M-5	8.50	N-5	3	O-5	2.35
D-13	10	E-13	10	F-13	10	M-6	0.35	N-6	10	O-6	0.20
G-1	25,000	H-1	30,000	I-1	25,000	P-1	12,000	Q-1	9,500	R-1	6,000
G-2	24,000	H-2	30,000	I-2	14,000	P-2	—	Q-2	1,500	R-2	1,750
G-3	9,500	H-3	9,500	I-3	5,500	P-3	175	Q-3	200	R-3	200
G-4	—	H-4	—	I-4	—	P-4	32	Q-4	32.20	R-4	43
G-5	—	H-5	—	I-5	—	P-5	2.20	Q-5	1.90	R-5	2.50
G-6	—	H-6	—	I-6	—	P-6	10	Q-6	0.20	R-6	0.20

rates of 1 r/sec and 107 r/sec for equivalent total exposure. The neutron sensitivities of the film emulsions were relatively low and could be considered to consist of two components: the response to low-energy (thermal) neutrons and the response to high-energy neutrons. As far as could be determined from this experiment, the two responses were independent and additive components. The neutron flux data for this calibration was furnished AFSWC by N-2 division at LASL. Neutron sensitivity values were compared to the amount of Co^{60} radiation required to produce the same optical density in the film emulsion. The assumption was made that any perturbation of neutron flux caused by the NBS holder was negligible.

The neutron corrections reported in the tables are based on neutron-flux measurements reported in References 10 and 11 and applied using the methods of Reference 9. For that portion of the correction due to slow (Au) neutrons, Reference 10 neutron data was used in connection with appropriate correction factors from Table 2.1. Unfortunately, the high-energy neutron correction factors of Table 2.1 were not in a readily usable form, having been determined as a percentage of neutron rep dose. The rep values were computed from $(rep)_0$ intercept values and effective neutron mean free path (λ) given in Reference 9 and utilizing the formula:

TABLE 3.8 GAMMA EXPOSURE, SHOT 8

Distance	Exposure	
Slant Range	Uncorrected (Co^{60} Calibration)	Betatron Corrected
yd	r	r
1,410	347	280
1,509	225	180
1,609	147	120
1,708	100	80
1,808	67	56
1,858	55	44
1,908	47	38
1,958	39	31
2,007	32	25
2,057	24	20
2,107	20	15
2,107	14	12

$$Rep = \frac{(rep)_0}{d^2} e^{-d/\lambda}$$

where d is the slant range, in yards, to the gamma station in question.

3.2 RESULTS

Examination of the zero intercept per kt (I_0/kt) values of Table 3.15 shows that I_0/kt for each event (except Shot 2) is greater than the I_0 deduced from Reference 1 for a 1-kt weapon detonated at an air density of one gram per liter (Figure 3.14). The mean free paths computed from the normalized RD^2-versus-D curves for each shot deviate somewhat from the mean free path of the curve in Figure 3.14; specifically for Shots 5, 8, 4, 3, 9, 11, and 10 this deviation amounted to 9, 10, 12, 14, 17, 17, and 25 percent, respectively.

3.2.1 Shots 1, 9, and 10. The slant ranges for Shot 10 were measured from the burst point to the canisters at the time of detonation. The normalized curves in Figure 3.4 indicate a gam-

TABLE 3.9 GAMMA EXPOSURE, SHOT 9

Project 39.7 chemical dosimeter data supplied by S. Sigoloff, School of Aviation Medicine, Randolph Field, Texas.

Distance	Exposure	
Slant Range	Uncorrected (Co^{60} Calibration)	Betatron Corrected
yd	r	r
280	70,000	—
380	28,500	—
461	16,000	—
522	10,000	—
603	6,300	—
709	3,200	—
837	1,500	—
943	880	—
997	660	—
1,044	580	—
1,098	410	—
1,154*	295	242
1,161	300	—
1,225	225	—
1,252*	200	164
1,333	140	—
1,349*	131	106
1,449*	85	69
1,546*	54	46
1,646*	34	29
1,744*	23	19
1,844*	15	14

* NBS film dosimeter data.

TABLE 3.10 GAMMA EXPOSURE, SHOT 10

Project 39.7 chemical dosimeter data supplied by S. Sigoloff, School of Aviation Medicine, Randolph Field, Texas.

Cannister Number	Distance	Exposure		
	Slant Range	Uncorrected (Co^{60} Calibration)	Betatron Corrected	Betatron and Neutron Corrected
	yd	r	r	r
3	310	187,000	—	—
5	397	108,000	—	—
6	497	60,400	—	—
7	542	44,000	—	—
8	678	26,000	—	—
8	678*	27,300	24,100	20,810
9	863	15,000	—	—
9	863*	13,000	11,500	9,825
10	1,040	7,550	—	—
10	1,040*	8,800	7,800	6,850
11	1,235	5,000	—	—
11	1,235*	5,500	4,900	4,401
12	1,385	3,200	—	—
13	2,440	400	—	—
13	2,440*	345	287	257
14	3,320	90	—	—
14	3,320*	85	78	69
15	4,213*	30	26	23

* NBS film dosimeter data.

TABLE 3.11 GAMMA EXPOSURE, SHOT 11

Distance Slant Range	Uncorrected (Co^{60} Calibration)	Exposure Betatron Corrected	Betatron and Neutron Corrected
yd	r	r	r
316	20,000	17,700	12,520
412	8,800*	8,300	6,320
510	7,900*	6,600	5,700
608	1,500*	1,450	1,055
905	390	326	280
955	355	300	260
1,025	265	220	190
1,100	184	152	—
1,177	125	103	—
1,204	105	88	80
1,259	84	69.5	—
1,342	58	48.0	—
1,427	40	33.0	—
1,516	26	21.5	—
1,606	15	12.0	—
1,696	10	9.1	—
1,787	6.5	6.0	—
1,878	5.3	4.4	—

* This data is questionable (see appendix).

TABLE 3.12 GAMMA EXPOSURE, SHOT 12

Distance Slant Range	Uncorrected (Co^{60} Calibration)	Exposure Betatron Corrected	Betatron and Neutron Corrected
yd	r	r	r
1,009	4,800	4,300	4,075
1,108	2,600	2,300	2,172
1,456	670	560	—
1,506	530	440	—
1,556	440	370	—
1,606	300	265	—
1,655	265	220	—
1,705	226	190	—
1,755	190	160	—
1,805	141	120	—
1,855	123	102	—
1,905	100	84	—
1,955	86	72	—
2,004	67	56	—
2,096	49	39	—
2,196	33	27.5	—
2,304	24	20	—
2,404	15	14	—
2,603	9.1	7.9	—
2,703	6.6	5.7	—
2,803	4.9	4.3	—
2,903	3.7	3.1	—
3,003	2.6	2.2	—
3,103	1.9	1.6	—
3,203	1.4	1.2	—
3,303	1.12	0.93	—
3,403	0.80	0.66	—
3,502	0.65	0.54	—
3,602	0.45	0.38	—

TABLE 3.13 CANISTER POSITIONING DATA AND FILM NORMALIZATION DATA FOR SHOT 10

Canister	Slant Range	Height	Average Density	Normalized Distance
	yd	yd MSL	g/cc × 10^3	yd
BP	0	12,207	344	0
3	310	12,297	341	106
4	318	12,245	342	109
5	397	12,313	341	135
6	497	12,313	339	168
7	542	12,411	339	184
8	678	12,473	338	229
9	863	12,545	336	290
10	1,040	12,633	334	348
11	1,235	12,620	334	413
12	1,385	12,688	333	461
13	2,443	13,141	324	794
14	3,322	13,565	312	1,068
15	4,213	13,988	302	1,273

TABLE 3.14 DOSE-TIME DEVICE DATA

The slant range of the device on Shot 9 was 863 yd and on Shot 10 was 1,385 yd.

Shot	Time of Start*	Exposure	Total Exposure†
	sec	r	pct
9	2	42.8	100
	8	23.0	53.8
	12	10.6	24.8
	15	—	—‡
	20	9.45	22.0
10	2	42.8	100
	8	34.5	80.5
	12	33.0	77.0
	15	31.7	74.0
	19	—	—§

* Time of start is with reference to the burst time.

† Percentage of total exposure is referred to the exposure received from the first dosimeter.

‡ Accidentally shorted during removal.

§ Shock repositioned the shut-off switch in a manner which caused the motor to stop prior to completion of the cycle.

TABLE 3.15 DEVICE DATA AND RESULTS

Shot Number	Name	Type	Diameter	High Explosive Thickness	Yield	Air Density	Zero Intercept RD^2		Apparent Mean Free Path		Apparent Mass Absorption Coefficient
							I_0	I_0/kt	(from data curves)	(from normalized curves)	
			inch	inch	kt	gm/liter	r × yd^2	r × yd^2	yd	yd	cm^2/gm
1	Wasp				1.2	1.116	2.3×10^9	1.9×10^9	365	406	0.0267
2	Moth				2.5	1.143	3.0×10^9	1.2×10^9	370	410	0.0263
3	Tesla				7.0	1.122	18.5×10^9	2.65×10^9	313	365	0.0311
4	Turk				43.0	1.091	110.0×10^9	2.55×10^9	330	363	0.0303
5	Hornet				3.6	1.118	8.4×10^9	2.33×10^9	329	376	0.0296
6	Bee				8.1	1.100	17.2×10^9	2.12×10^9	385	413	0.0283
7	ESS				1.2	—	—	—	—	—	—
8	Apple				15.0	1.060	33×10^9	2.2×10^9	348	372	0.0296
9	Wasp′				3.1	1.048	13×10^9	4.2×10^9	331	344	0.0314
10	HA				3.1	0.343	25.0×10^9	8.1×10^9	952	308	0.0340
11	Post				1.53	1.097	5.7×10^9	3.7×10^9	313	344	0.0317
12	MET				24.0	1.068	63×10^9	2.63×10^9	361	391	0.0284
(Computed from Reference 1)					1	1.00		1.86×10^9		413	0.0263

ma exposure from Shot 10 that is about the same as the exposure from the correlative event, Shot 9, while the apparent mean free path decreases by 11 percent from 345 yards for Shot 9 to 308 yards for Shot 10. Comparison of readings in and out of the drop canisters on Shots 1 and 9 (Shot 1 was intended as the correlation for Shot 10) show effects of neutron-induced gamma activity in the canister materials, probably the aluminum windows. This is corroborated by gamma-rate data obtained by Projects Teapot 2.4 and Plumbbob 2.5. Shot 1 data gives an 11-percent increase in apparent gamma exposure, inside over outside, at 760 yards but shows no difference at 980 and 1,070 yards, indicating primary transmission through the aluminum windows. Shot 9 data similarly shows a 30-percent increase at 675 yards and 11 percent increase at 860 yards.

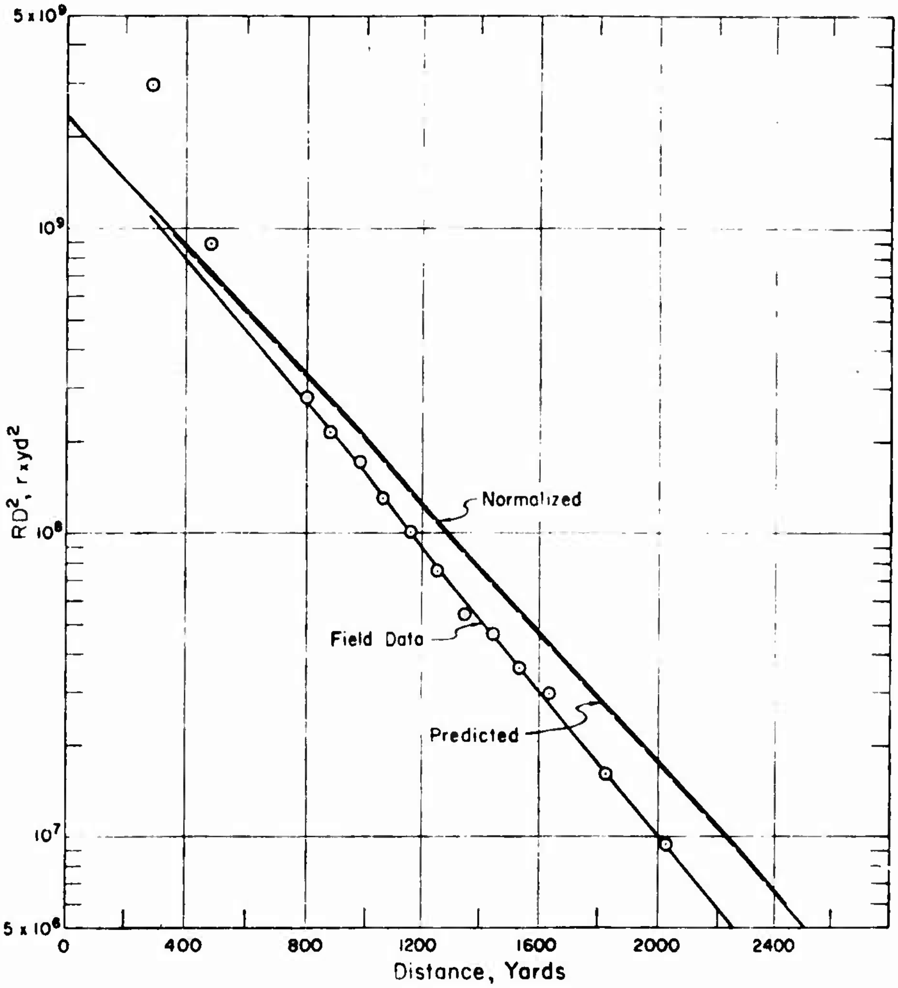

Figure 3.1 RD^2 versus D, Shot 1.

Laboratory tests with Co^{60} show negligible gamma attenuation due to the aluminum windows and approximately 13 percent attenuation due to the steel wall of the canister. The planned neutron-effects calibration was not completed because of scheduling difficulties (Reference 10).

Based on the above analysis and the data given in Table 3.13, the data (after all corrections, see Table 2.1) from the first ten recovered canisters (3 through 12) may be high by about 30 percent, and the data from Canisters 13, 14, and 15 is good to within 10 percent.

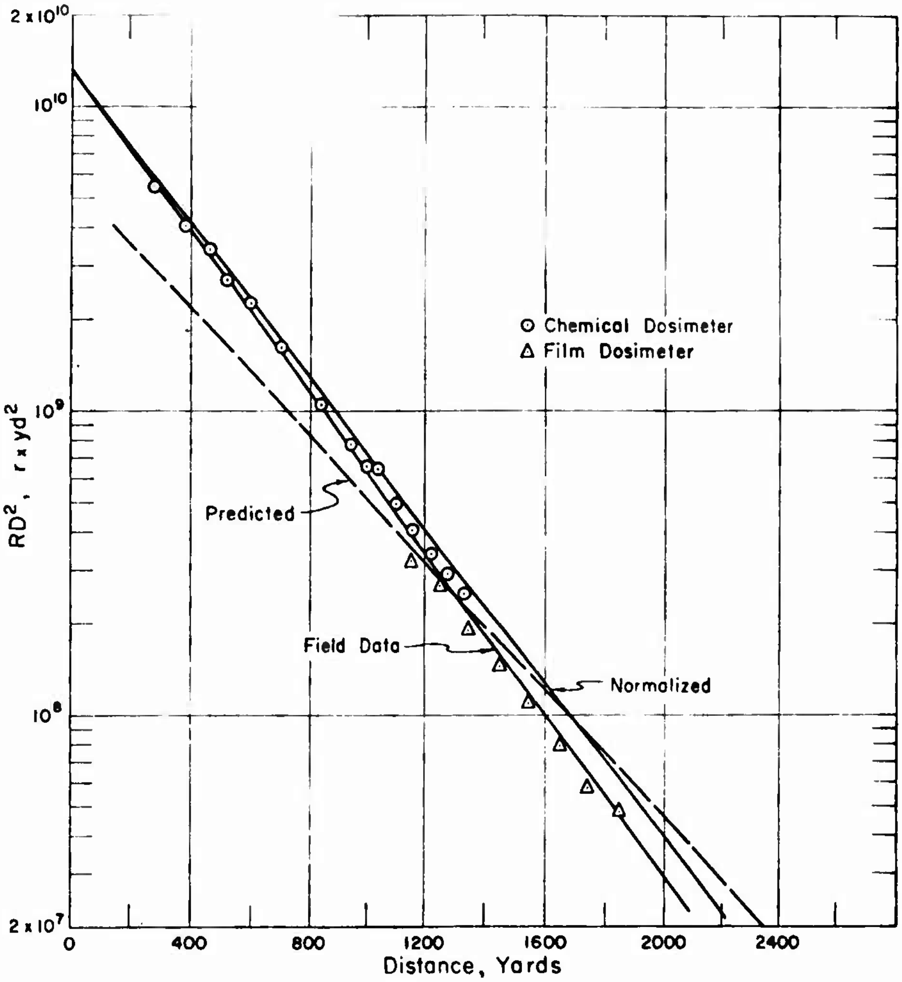

Figure 3.2 RD^2 versus D, Shot 9.

Since the canisters on Shot 10 were distributed from the burst height of 36,620 ft MSL to 42,201 ft MSL, the average air density from the point of detonation to the canister was different in each case. Thus a different normalization factor was computed for each canister at the time of burst as shown in Table 3.13.

The data obtained from the Bendix IM-93 style quartz fiber dosimeters for Shots 9 and 10 are

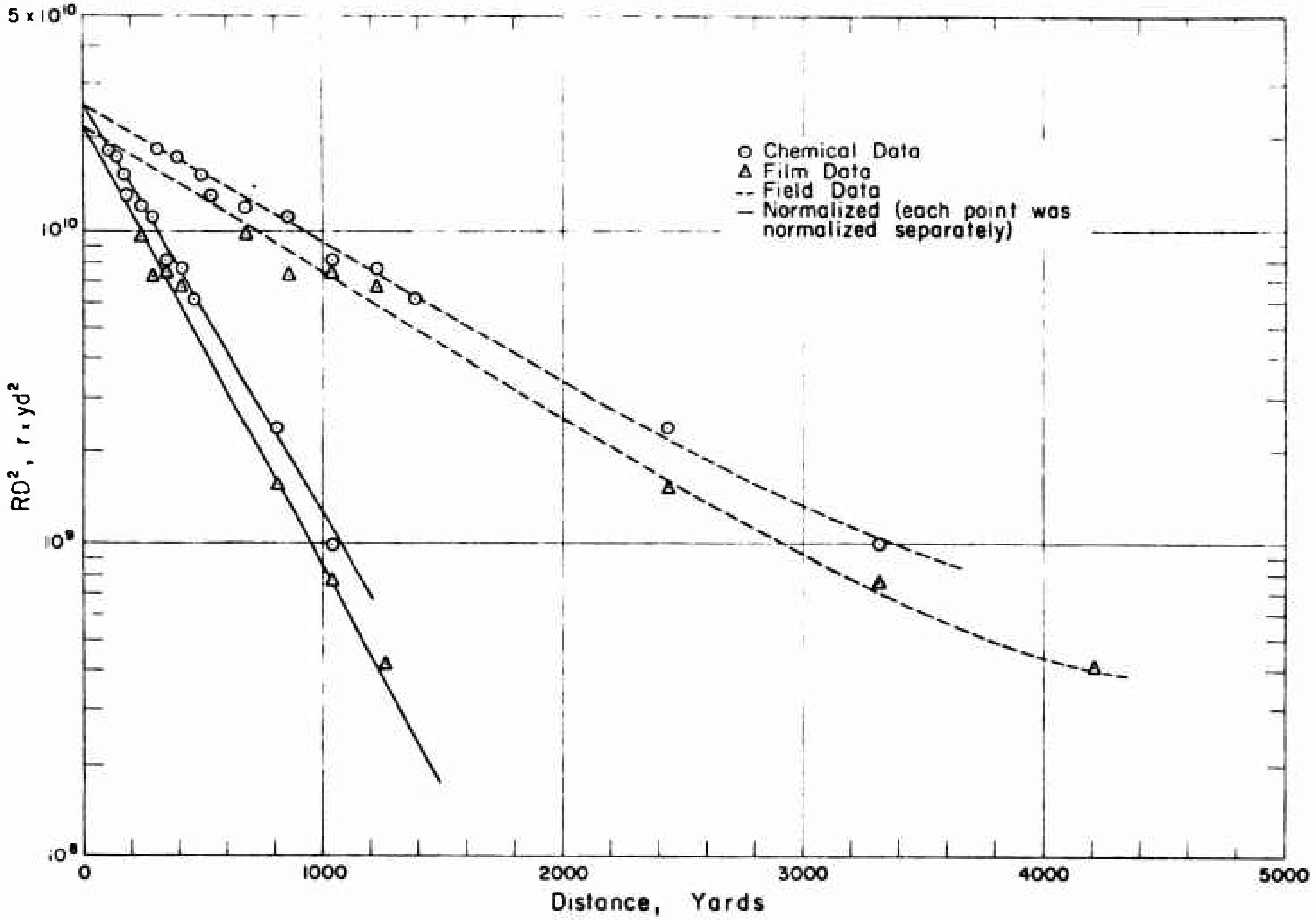

Figure 3.3 RD^2 versus D, Shot 10.

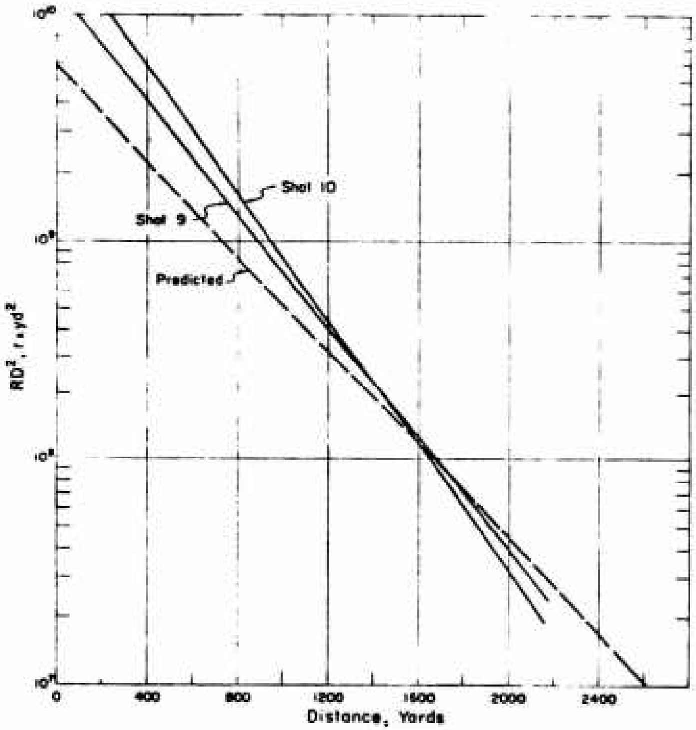

Figure 3.4 Normalized RD^2 versus D, Shots 9 and 10.

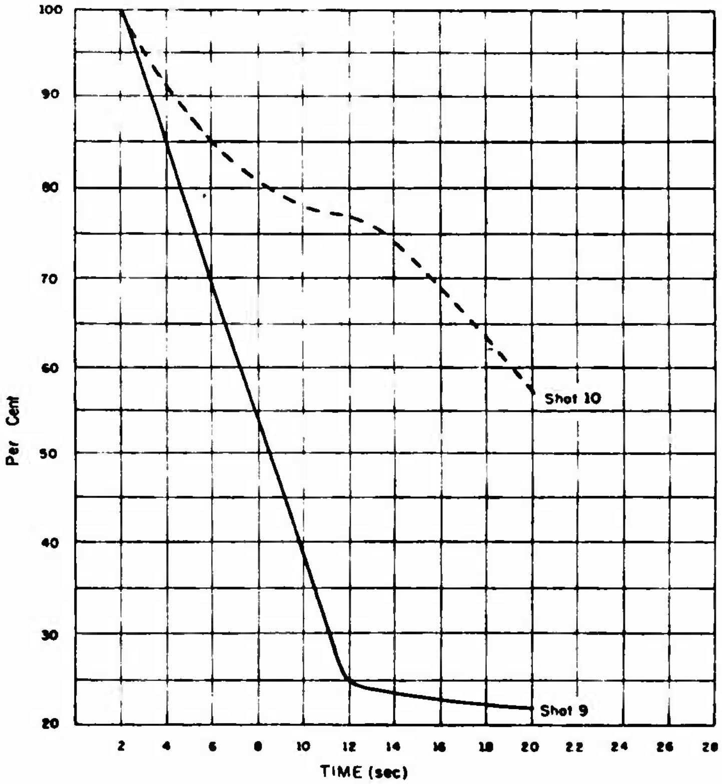

Figure 3.5 Comparison of exposure versus time, Shots 9 and 10.

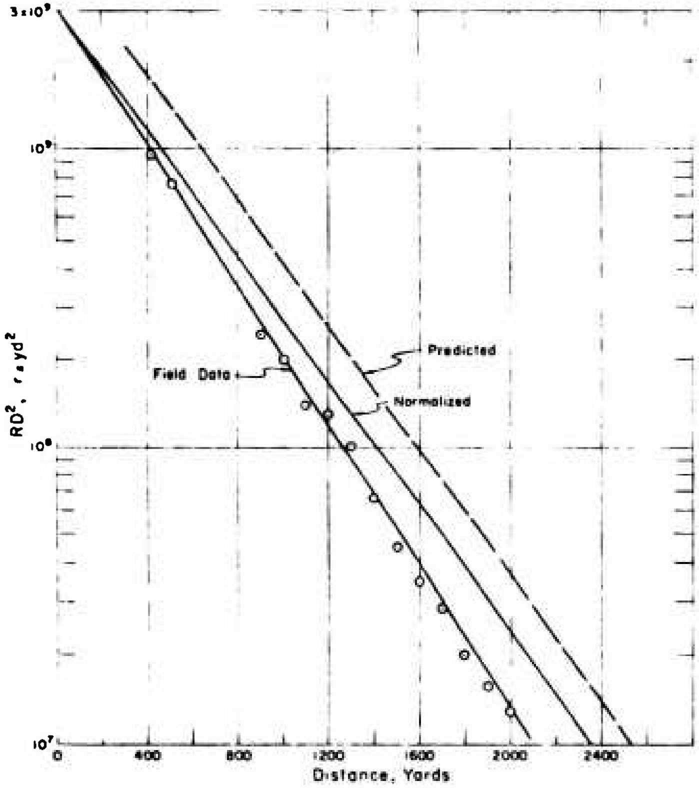

Figure 3.6 RD² versus D, Shot 2.

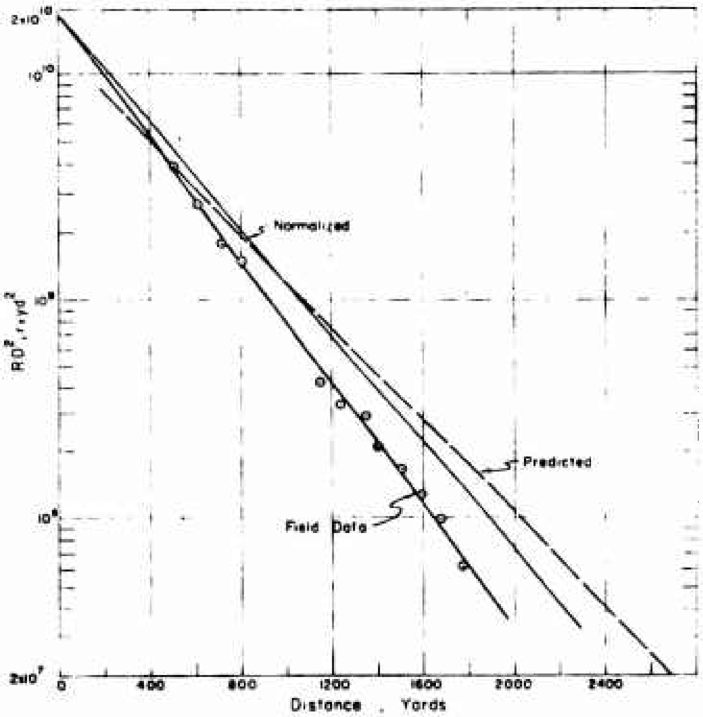

Figure 3.7 RD² versus D, Shot 3.

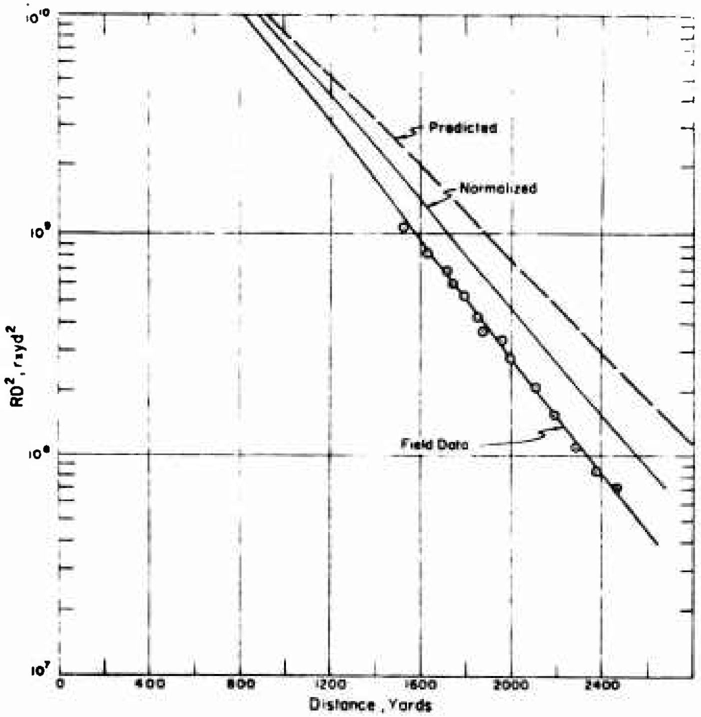

Figure 3.8 RD^2 versus D, Shot 4.

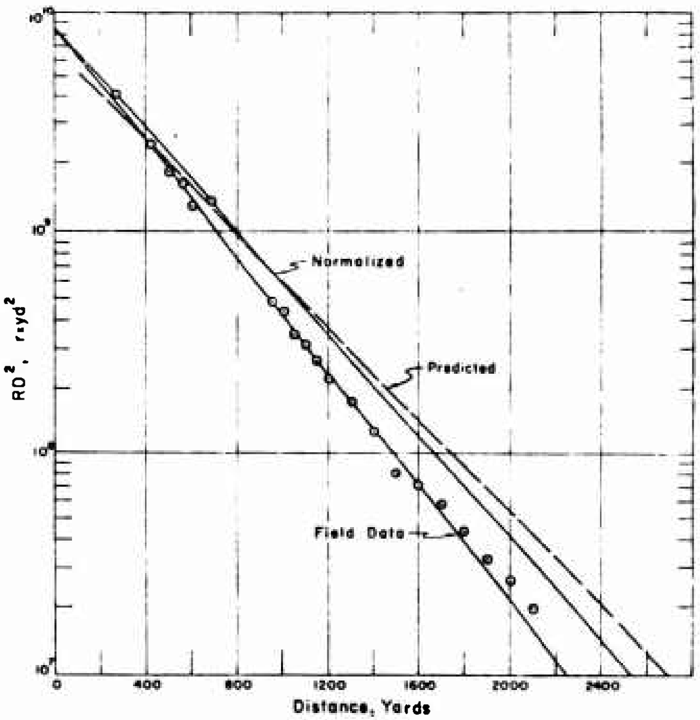

Figure 3.9 RD^2 versus D, Shot 5.

reported in Table 3.14. A plot of the percentage of the exposure received versus the time after which the exposure was received is plotted in Figure 3.5 for Shot 10 and the correlative shot. Two of the instruments, placed in Canisters 4 and 8 on Shot 10, failed to operate, seemingly due to a failure to receive the 6-volt signal at the time of release of the canisters from the strike aircraft. Therefore, only one curve is plotted for Shot 10. Since complete data were not obtained, a definite conclusion cannot be drawn, but the two curves indicate that there may have been a contribution from the cloud for a greater time for Shot 10 than was noted for the correlative shot.

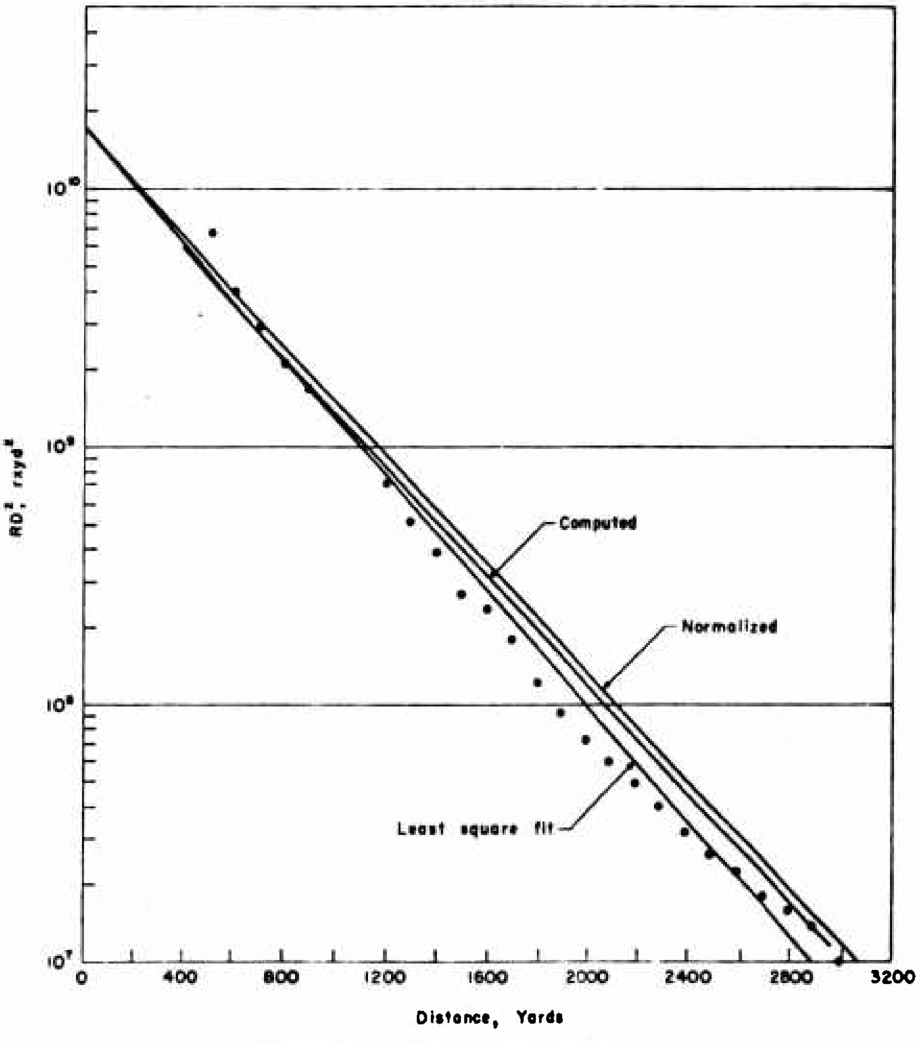

Figure 3.10 RD^2 versus D, Shot 6.

The exposures received at the close-in stations on Shot 10 were beyond the range of film. In

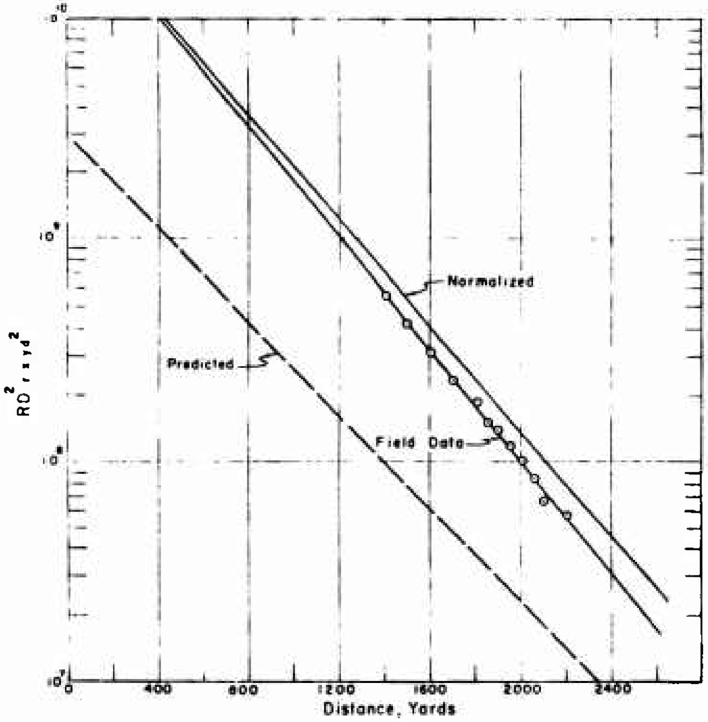

Figure 3.11 RD^2 versus D, Shot 8.

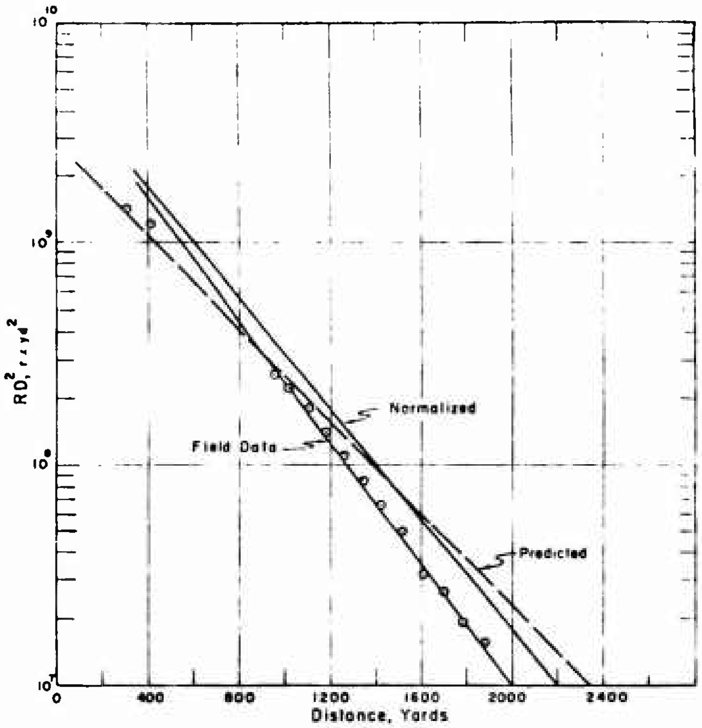

Figure 3.12 RD^2 versus D, Shot 11.

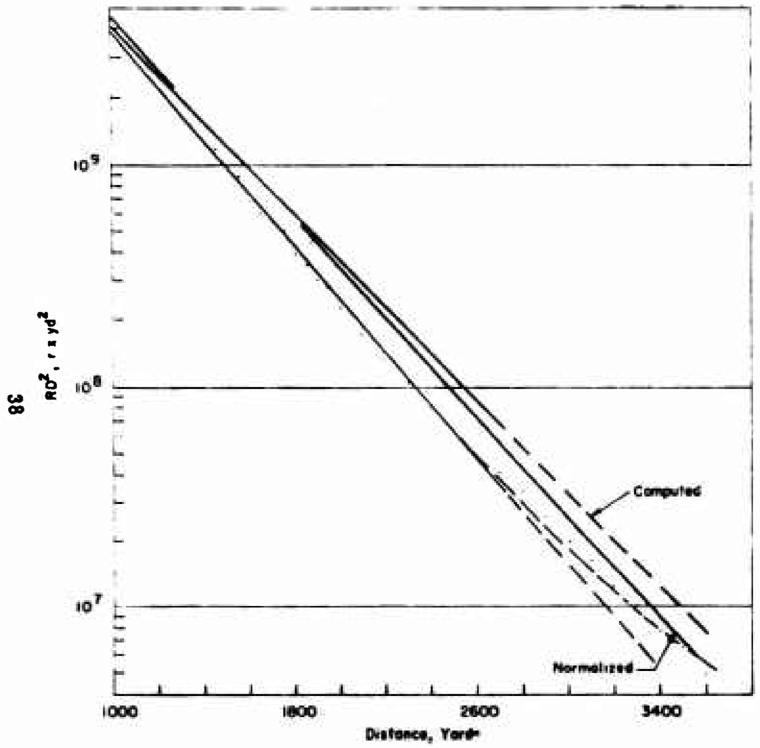

Figure 3.13 RD^2 versus D, Shot 12.

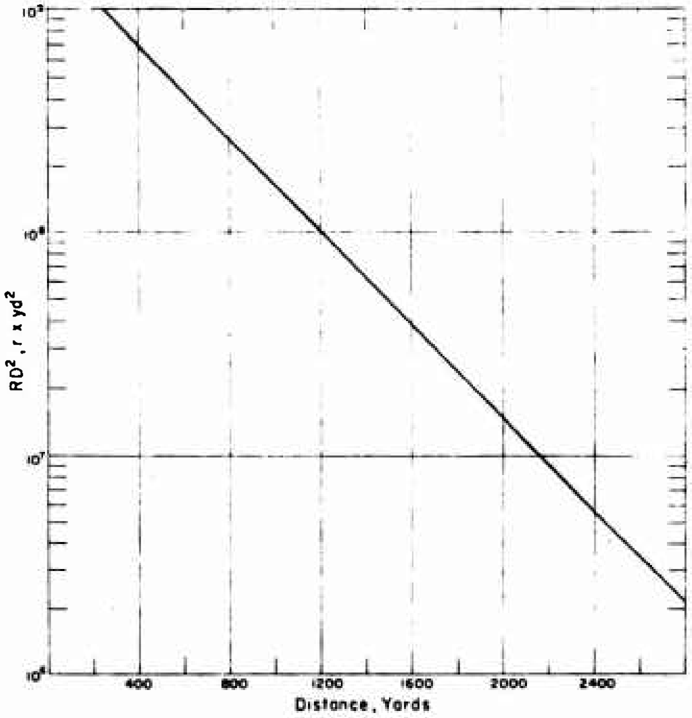

Figure 3.14 RD^2 versus D, 1 kt.

addition, some of the exposed film from Shot 9 was lost in a laboratory accident. Therefore, chemical dosimeter (Reference 1) data were plotted in Figures 3.2 and 3.3, to further substantiate the curves resulting from the film data.

3.2.2 Shots 2, 3, 4, 5, 6, 8, 11, and 12. Dosimeter lines were placed out in four directions from ground zero on Shots 3 and 11 [redacted] On Shot 3, only the data obtained south of ground zero are reported because unexpected fallout in the area north of ground zero prevented recovery and processing of these film badges before the residual gamma field had produced a large, unmeasured gamma exposure on them. On Shot 11, some data was obtained on each of three lines (1) one line normal, (2) one line at 45 degrees and (3) one line parallel to the linear axis of the device. This data is presented in the Appendix.

[redacted] However, due to small quantity of data, and the accuracy limits of the film dosimeters, coupled with the lack of precision of the neutron corrections, it is felt that no positive statement can be made on this point.

The usual dosimeter lines in a single radial direction were placed and recovered for the other shots. The data is given for each shot in the appropriate table. Participation in Shots 4, 8, and 12 was primarily for correlation of the results of the dosimeter-evaluation Projects 6.1.1 and 39.6.

The apparent mean free paths for these events varied over a range of about 20 percent. In general, gamma radiation from these devices had short apparent mean free paths in comparison to those computed from Reference 1. The shots for which these deviations are noticed are [redacted] devices (Table 3.15) from which a different gamma exposure versus distance may be expected.

3.2.3 Support. The total gamma exposures for Shot 7 (in support of Project 2.5.1 at their stations located as shown in Figure 2.2) are tabulated in Table 3.7. Total dose contours prepared by Project 2.5.1 are shown on page 38, WT-1119. Results obtained in support of other projects were reported directly to the requesting project and are not included in this report.

A portion of the results and the support data for Shots 7, 8, and 9 were destroyed by a laboratory accident.

3.3 ACCURACY

Based upon information supplied by NBS, the overall accuracy of the reported exposure readings is considered to be within ± 30 percent.

Chapter 4

CONCLUSIONS

The effective gamma yield of the low-kt yield, high-neutron-flux experimental devices measured on Operation Teapot does not scale with the kt yield in the same way as the standard low-yield (under 10 kt) weapons given in Reference 1.

S.I The initial gamma measurements made for a device detonated at 36,620 feet above MSL and for an identical device detonated at 4,995 feet above MSL, when normalized to the reference air density of 1 gram per liter, indicate approximately equal gamma exposures at equivalent distances. However, the apparent mean free path for the 36,620-foot detonation was 11 percent shorter than the mean free path for the 4,995-foot detonation.

The maximum possible asymmetry in the initial gamma flux from a [redacted] weapon is less than 20 percent, based on measurements made on Shot 1[redacted]

Appendix

GAMMA SYMMETRY

On Shot 11, film dosimeter data was obtained from some stations, oriented with respect to the [redacted] device as shown in Figure A.1. This data has been corrected by a betatron recalibration and for effects of neutrons. The methods used for these corrections are given in the basic report. The complete data is presented in Table A.1. The data from stations at 412, 510 and 608 yards are questionable because of the fact that the emulsions used at these stations were exposed below or above their normally used ranges.

TABLE A.1 GAMMA SYMMETRY DATA, SHOT 11

Slant Range	Exposure			
	Average	W (0 Deg)	F (45 Deg)	S (90 Deg)
yd	r	r	r	r
316	12,500	12,500	—	—
412*	6,320	6,000	6,000	6,950
510*	5,700	5,700	—	—
608*	1,055	1,030	1,080	—
707	Lost	—	—	—
806	Lost	—	—	—
905	280	280	—	—
1,005	190	175	200	200
1,204	80	75	80	85

* Data from these stations is questionable.

Although the data shown in Table A.1 indicates a consistent increase in exposure value in [redacted] the deviation is slight and less than the probable error limits of any film measurement.

The asymmetry in the neutron flux as reported in Reference 10 caused the neutron-corrected, film-exposure readings to show less deviation than the uncorrected (Co^{60} field calibration) exposure readings. The limited data available, in the light of the probable errors, does not justify a positive statement concerning the magnitude of any asymmetry of the gamma flux from a [redacted] device except that any asymmetry amounts to less than 20 percent.

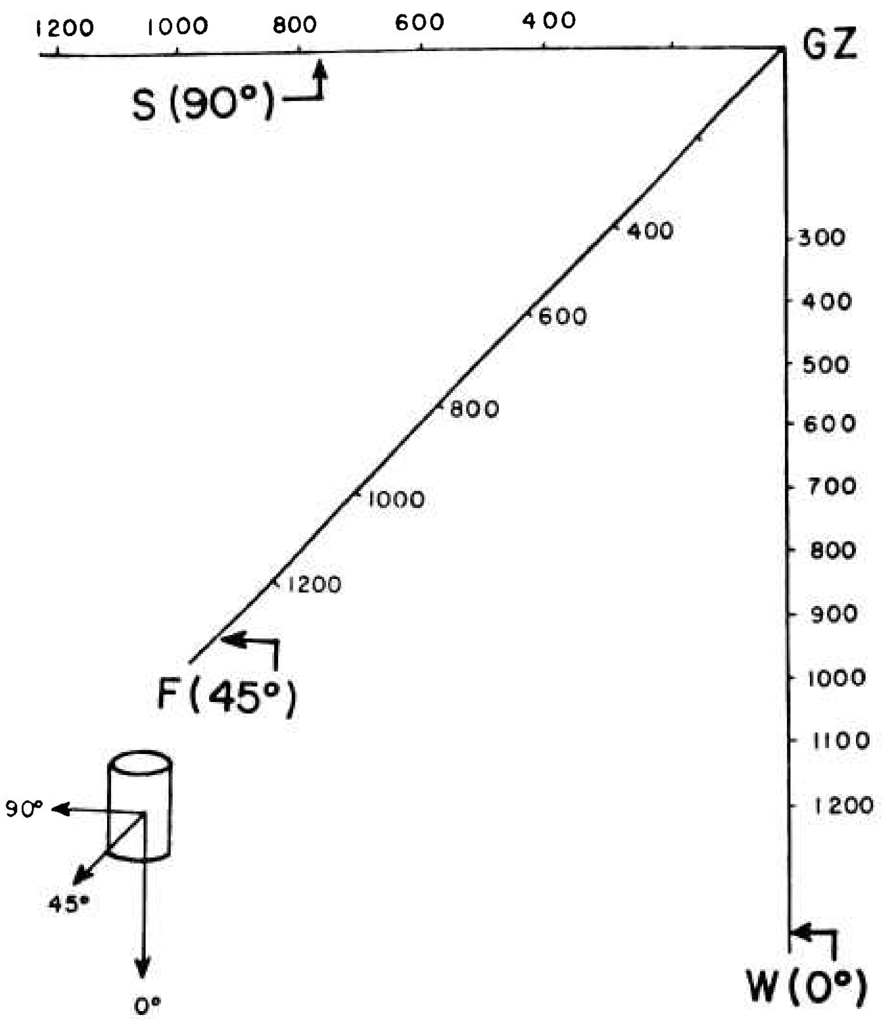

Figure A.1 Station layout, Shot 11.

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